Synthesis and characterization of cobalt oxide, vanadium oxide, and cobalt/vanadium oxide for electrochemical supercapacitor applications

Synopsis in Candidature for the Degree of
Doctor of Philosophy in Physics

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Submitted to

Swami Ramanand Teerth Marathwada University, Nanded

2021-2022

1. Introduction

There are two significant effects of rising fossil fuel usage brought on by the expansion of the world economy. The first is the quickening of the depletion of fossil fuel reserves, and the second is related to environmental issues brought on by an increase in greenhouse gas emissions and water and air pollution. All of these factors highlight the need to research and develop innovative energy storage technologies as well as alternate, sustainable, and clean energy sources. The most popular energy storage technologies in this context are batteries and supercapacitors [1-2].

Recently, supercapacitors have gained great attention in the energy storage field owing to their ability to quickly charge storage ability and release large amounts of energy. This exceptional speed is explained by surface reactions of the electrode materials that do not require ion diffusion into the bulk of the materials. Additional interest lies in their long life cycle with respect to the batteries [3]. Batteries have lower power densities and higher densities as compared to supercapacitors. A supercapacitor has a higher power density than batteries. Therefore, they are good candidates for applications such as electric vehicles, consumer electronic devices, military equipment, and power backup systems. Nevertheless, what hinders their use on a larger scale is the poor energy density. Supercapacitors are replacing traditional electric car batteries with quick charging and temperature stability. Additionally, supercapacitors are more flexible than standard batteries. The high demand for a stable power supply for applications, such as GPS, portable media players, laptops, and mobile devices, is an emerging trend in the market studied.

2. Literature review

The two main groups into which electrochemical capacitors can be divided according to their charge/discharge mechanism are electrical double layer capacitors (EDLC), which operate by the accumulation/diffusion of charges at the interface of the electrode, and pseudocapacitors, which store charge through highly reversible faradaic reactions in the electrode material.

While transition metal oxide electrodes such as MnO_2 [4], RuO_2 [5], Fe_2O_3 [6], NiO [7], Bi_2O_3 [8], and composite with these metal oxides [9] are most frequently employed in pseudocapacitors, carbon has long been the primary electrode material for EDLC [10]. The metal oxides have shown promising results in the past years due to their high capacitance compared to carbon. Although RuO_2 presents great performance, its exploitation is limited due to its high price. That is why other oxides such as V_2O_4, Co_3O_4, were studied as a good alternative, due to its very high theoretical

capacitance, its better electronic conductivity, and its lower cost. However, the major drawback of cobalt oxide and vanadium oxide is related to the poor cyclability and structural rigidity due to the swelling and shrinking during cycling.

In order to encompass this drawback, the nano-structure of cobalt oxide and vanadium oxide has been foreseen as an interesting alternative to other metal oxides. Numerous morphologies on the nanoscale have been synthesized for supercapacitor applications [11–12].

Nevertheless, cobalt oxide electrode (CO_3O_4) and vanadium oxide (V_2O_4) materials still suffer from limited electron transport rates, leading to low power density and capacity fading. For this purpose, composites made of cobalt oxide, vanadium oxide nanoparticles, and carbonaceous materials have been explored as a good combination to improve the electrical conductivity, increase the specific surface area, and limit the aggregation of metal oxide nanoparticles [13]. The capacitance could be improved via the EDLC mechanism in addition to the pseudocapacitive one. Thus, the association of carbon and cobalt oxide with vanadium oxide is very promising to achieve better performance under different testing regimes.

3. Aim

The focus of present work is to develop cobalt oxide, vanadium oxide, and composite of cobalt-vanadium oxide based asymmetric and asymmetric supercapacitors based on composite nanostructures. These asymmetric supercapacitors consist of a battery-type Faradaic electrode (as the energy source) and a capacitor-type electrode (as the power source), simultaneously offering the advantages of both supercapacitors (rate, cycle life) and advanced batteries (energy density). Therefore, asymmetric supercapacitors can make full use of the different potential windows of the two electrodes to provide a maximum operation voltage in the cell system, accordingly resulting in a greatly enhanced specific capacitance and significantly improved energy density.

4. Objective

The main objective of the proposed synopsis is to develop and synthesis novel cobalt oxide, vanadium oxide, and composite of cobalt-vanadium oxide based electrodes for super capacitors performance.

- Synthesis of 3D structured cobalt oxide electrodes.
- Synthesis of vanadium oxide electrodes.
- Structural and morphological properties of the prepared cobalt oxide and vanadium oxide-based nanostructured electrodes will be studied using various characterization techniques

such as X-ray diffraction (XRD), field emission scanning electron microscope (FE-SEM), high resolution transmission electron microscopy (HR-TEM), X-ray photoelectron spectroscopy (XPS), energy dispersive X-ray spectroscopy (EDS), Fourier Transform Infrared Spectroscopy (FTIR), Raman Spectroscopy, etc.

- Obtained high specific capacitance, cyclic life, excellent rate capability.
- Fabrications of symmetric and asymmetric supercapacitor.
- Work will have published in reputed journals.

5. Synthesis method

Many chemical methods are used for the synthesis of cobalt oxide and vanadium oxide based and composite electrodes, such as hydrothermal deposition (HD), chemical bath deposition (CBD), electrodeposition (E-D), successive ionic layer adsorption and reaction (SILAR), sol-gel, and spray pyrolysis deposition (SPD), which have frequently been used to obtain cobalt oxide and vanadium oxide based nanostructures in both film and powder form. These vacuum-free chemical methods do not require complex and expensive instrumentation. A few methods are as follows:

CBD (Chemical bath deposition)

The metal oxide/bi-based electrode prepared by adjusting CBD preparative parameters, such as deposition temperature, time, pH, complexing agent etc. The metal oxide films were deposited from the solution-containing precursor by using different complexing agent.

SILAR (successive ionic layer adsorption and reaction)

SILAR method is economically, highly feasible for large area deposition and wastage of chemicals can be avoided. For the deposition of material thin film, a well-cleaned glass substrate was immersed in the cationic precursor solution, causing cations to be adsorbed on the surface of the glass substrate. This substrate was immersed in an ample amount of double distilled water to prevent homogenous precipitation. The substrate was then immersed in the anionic precursor solution. Anions reacted with the adsorbed cations on the glass substrate. The substrate was then immersed in double-distilled water.

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Hydrothermal

Many types of nanomaterial/metal oxide have been successfully synthesized by using hydrothermal. There are significant advantages of hydrothermal synthesis method over others. Hydrothermal synthesis can generate nanomaterial which are not stable at elevated temperatures. Nanomaterial with high vapor pressures can be produced by the hydrothermal method with minimum loss of materials. The compositions of nanomaterial to be synthesized can be well controlled in hydrothermal synthesis through liquid phase or multiphase chemical reactions.

Among these methods, optimized method will be used for synthesis of bi-based electrodes for supercapacitor application.

6. Experimental section

Synthesized cobalt oxide and vanadium oxide based electrodes will be characterized by using different analytical tools and techniques such as X-ray diffraction (XRD), Raman spectroscopy, Fourier Transform Infrared Spectroscopy, Field Emission Scanning Electron Microscopy (FE-SEM), High Resolution Transmission Electron Microscopy (HR-TEM), X-ray photoelectron spectroscopy (XPS), energy dispersive X-ray spectroscopy (EDS), etc.

An electrochemical workstation will be used to study the electrochemical properties and device fabrication. Finally, carried work will be submitted to the university for the award of a Ph.D. in the form of a thesis.

7. Outcomes:

- A supercapacitor device will be fabricated using cobalt oxide and vanadium oxide-based electrodes.
- The results will be published in the reputed journals.

8. Work plan

The proposed work will be carried out in following phases;

Phase – I (First Year)

- In the first year, a literature survey will be carried out. The various cobalt oxide and vanadium oxide based and composite electrodes materials will be prepared using suitable synthesis methods.

Phase – II (Second Year)

- The electrochemical performance of the prepared electrodes will be measured and studied in different electrolytes such as KOH, H_2SO_4, NaOH, KCL, etc.
- Rate performance, voltage window, and stability will be evaluated.

Phase – III (Third Year)

- The symmetric and asymmetric devices will be fabricated to investigate the industrial potential of the prepared metal sulfides.
- The work will be published in the form of research manuscripts in high impact research journals.

9. References

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